NAVAL HEALTH RESEARCH CENTER

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Report No. 97-9

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Report No. 97-9, supported by the Naval Medical Research and Development Command Department of the Navy and the U.S. Air Force, under Research Work Unit No. U.S. Air Force Reimbursable-6515. The views expressed in this article are those of the authors and do not reflect official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government. Approved for public release, distribution unlimited. Human subjects participated in this study after giving their free and informed consent. Investigators adhered to NAVHLTHRSCHCENINST 6500.2, 2 Aug 95, concerning the protection of human volunteers in medical research. The assistance of EM3(SW/DV) Victor Ramirez and BM3(DV) Timothy Alexander as subject volunteers and HM3 Venus Valencia and Stacy Stanley as research technicians for this study is acknowledged and appreciated. The authors also appreciate the help of Dr. Donald Hagan and Ms. Sue Sobanski for their review and technical assistance, respectively.

SUMMARY

Problem

Respiratory and eye protection is necessary to sustain life and required by military personnel in a chemical warfare environment. The use of a Disposable Eye/Respiratory Protection (DERP) hood and mask is proposed to provide head, eye, neck, and respiratory protection on an emergency basis when normal protective equipment is not immediately available. Prolonged work while wearing a protective chemical/biological mask in ambient temperatures (21°C to 24°C) has been shown to result in decreased endurance and subjective feelings of exertion and discomfort. Two of the important parameters affecting military work performance while wearing a chemical/biological mask are carbon dioxide (CO_2) and environmental stress.

Objective

The objective of this study was to evaluate three prototype DERP masks under consideration for use by the U.S. Air Force. The evaluation included measurement of CO_2 levels and breathing resistance inside these masks. Additionally, the thermal, physiological, and psychological effects of wearing the three masks during rest and exercise were measured during two 2-hr scenarios, once each under two different environmental conditions (heat and cold).

Approach

The experimental conditions simulated a 2-hr battlefield scenario, stipulated by the U.S. Air Force. The study was a 2 X 4 research design; two environmental extremes and four experimental sessions. The two environmental conditions were cold air (-29°C, 30% RH) and hot air (52°C, 30% RH). The experimental sessions consisted of a no-mask (the reference condition) and trials wearing three prototype masks (National Draeger [Draeger], ILC Dover [Dover], and Mine Safety Appliances [MSA]). The two subjects wore battle dress uniforms appropriate for the environment. The subjects entered the environment and sat unmasked for 15 min. The mask was then donned and the subject walked on a treadmill for 10 min at an energy expenditure of 500W, sat quietly for 100 min and walked again for 10 min at 500W. During the no-mask trials, oxygen uptake was collected by the Douglas Bag method during the last 5 min of each exercise segment and every 20 min of rest. During the mask-trials, timed measurements were made of CO_2 and breathing

resistance inside the mask. Heart rate, skin and rectal temperatures were recorded continuously throughout the trial. The Borg 15-Point Rating of Perceived Exertion (RPE) and Thermal Sensation (TS) were recorded during the test and immediately after each CO_2 and breathing resistance measurement.

Results

Neither subject was able to complete the 2-hr test in the heat due to the discomfort resulting from the combination of heat strain and layers of clothing worn. Cold exposure did not result in a remarkable level of cold strain. The MSA mask test in the cold concluded after 5 min during the rest period for one subject and after 30 min of rest for the second subject as a result of discomfort during mask wear. The Draeger and ILC mask experiments in the cold followed the complete 2-hr scenario.

The levels of CO_2 and breathing resistance were considered satisfactory inside the Draeger and MSA masks, whereas these indices for the ILC mask were unsatisfactory based on U.S. Air Force standards. Overall, the effects of wearing the masks on heart rate and body temperature, and subjective responses and feelings of exertion and comfort of the subjects were marginally satisfactory for the Draeger and unsatisfactory for the MSA and ILC.

Conclusion

The 2-hr scenario in the cold was well tolerated by the subjects; however the 2-hr scenario in the heat was too difficult. Physiological and psychological indices followed what would be expected in these environmental extremes. However, adding the stress of wearing a mask and the inability to hydrate caused several of the trials to end prematurely. Since some of the results met minimal physiological requirements as set forth by the U.S. Air Force, there is a need for a better designed disposable chemical/biological protection mask.

INTRODUCTION

The threat of chemical warfare associated with the war in the Persian Gulf revealed that there is insufficient information regarding environmental extremes facing U.S. military personnel who can be exposed to both high temperature and high humidity and chemical/biological attack. In a chemical warfare environment, both respiratory and eye protection are required. The standard mask currently used by the military is the bulky, heavy MCU-2/P. Respiratory indicators of performance for military personnel wearing the MCU-2/P such as minute ventilation and oxygen uptake have been determined to be more than adequate when testing for resistance to breathing and comfort as well as overall chemical/biological protection (Muza, 1986). The U.S. Air Force however has determined a need exists to study the effectiveness of the MCU-2/P in maintaining acceptable levels of carbon dioxide (CO_2) during exposure to environmental extremes. If CO_2 and resistance inside the mask were high, the personnel would have difficulty breathing, rendering the mask less acceptable.

There are currently three different prototypes of a Disposable Eye/Respiratory Protection (DERP) mask. The DERP mask is proposed as an emergency mask for U.S. Air Force personnel to escape a chemical environment and reach a collective protection shelter until long-term protection such as the MCU-2/P can be obtained. It is intended to be carried by ground crew personnel, aircrew members, and medical caregivers as a less bulky and cumbersome supplement to the current mask, not as an alternative. The U.S. Air Force required a demonstration of the functionality of these prototypes for a period of 2 hr at two temperature extremes (-29°C and 52°C).

Prolonged work in temperatures of 21°C to 24°C has been shown to result in a decrease in performance while wearing a protective chemical/biological mask. Stemler and Craig (1977) reported a 21% decrease in total running time at 16 km/hr while a chemical/biological mask was worn. Important parameters affecting military work performance while wearing a chemical/biological mask are CO_2 buildup, breathing resistance, and thermal stress.

A potential consequence of prolonged work while wearing a chemical/biological mask is fatigue of the respiratory musculature (Muza, 1986). During unencumbered exercise, endurance of the respiratory muscles does not appear to limit exercise performance. However, when breathing resistance is increased, as with the addition of a protective mask, the work of breathing also is increased. The greater force needed to overcome the resistance of the mask increases the energy

demands of the respiratory muscles, and the oxygen consumption for a given submaximal workload increases. Thus, the sustainable workload will be decreased when wearing a mask (Muza, 1986). A chemical/biological mask worn at rest has been shown to cause respiratory muscles to consume 5% to 6% of total-body oxygen consumption compared to 2% to 3% without a mask (Arad et al., 1991). During moderate exercise, oxygen consumption can increase more than 10% (Arad et al., 1991). In addition, should the wearer sweat as a result of exertion, the sweat can penetrate the filter and lead to further increases in inspiratory breathing resistance (Arad et al., 1991).

Because wearing a mask adds to the respiratory dead space, CO_2 builds up in the mask during normal ventilation. Four percent CO_2 is the generally accepted upper limit for CO_2 buildup (Cummings & Craig, 1958), and it is the upper exposure limit specified as acceptable by the U.S. Air Force. When breathing through the added resistance of a mask, ventilation decreases proportionally to the resistance (Muza, 1986). This hypoventilation results in an increased alveolar CO_2 which could decrease work output (Muza, 1986). In a study of 158 mine workers performing a 30-min walk, Bentley et al. (1973) found that breathing discomfort (dyspnea) was experienced by 10% of mask wearers as a result of the resistance to breathing.

During mask wear, the level of heat stress, sweat rate, skin temperature ($\bar{T}_{sk}$), and heart rate (HR), resulting from physiological and psychological strain increases (Muza, 1986). Wearing a chemical/biological mask and impermeable hood elevated sweat rate about 16% in a hot/dry environment and increased $\bar{T}_{sk}$ (Robinson & Gerking, 1945). Thermal stress can be increased by a decrease in heat loss through the head. However, when a mask is worn with a hood and/or helmet, heat loss is further decreased, causing about a 50% decrease in heat dissipation from the head. The decrease in heat dissipation can result in an increase in core body temperature (Muza, 1986). As a result of the reduced heat dissipation there is increased body heat storage which has been shown to decrease work performance (Muza, 1986).

The objective of this study was to evaluate three DERP masks under consideration for use by the U.S. Air Force. The level of CO_2 and breathing resistance inside these biological/chemical masks and thermoregulatory responses were analyzed while subjects underwent repeated bouts of rest and exercise in two environmental extremes.

MATERIALS AND METHODS

Subjects

Two males served as subjects. Subject 1 was 22 yrs, 173.7 cm and 70.7 kg. Subject 2 was also 22 yrs, 184.5 cm and 81.1 kg. The subjects were recruited from the Aviation Physiology and Water Survival Training Department at Naval Air Station, Miramar, CA. The subjects were experienced divers and were accustomed to wearing masks. They were briefed on the entire procedure, willfully provided an informed consent, learned about emergency procedures, practiced treadmill walking, donned and doffed practice masks, and became acquainted with data collection procedures.

Measurements

Masks. Three prototype DERP masks (National Draeger [Draeger], Dover ILC [ILC], and Mine Safety Appliances [MSA]) were supplied by the U.S. Air Force. The DERP systems were designed as single-size, disposable, emergency biological/chemical defense masks to provide protection for a maximum of 2 hr. The masks were vacuum-packed chemical defense hoods integrated with visors, nosecups, and filters. Two of each type of mask were provided for testing. Due to this limitation, only two subjects were used for the evaluation which did not allow formal hypothesis testing.

Exercise Clothing Ensemble. Two sets of uniforms were provided by the U.S. Air Force. In the heat, the subjects wore a battle dress uniform (BDU) and combat boots. The BDU consisted of wool socks, cotton underwear and undershirt, cotton camouflage trousers and blouse with the sleeves rolled down. In the cold environment, subjects wore the BDU, vapor barrier boots, arctic mittens, long wool underwear, and parka.

Scenario. A 2-hr scenario was designed by the U.S. Air Force to simulate an operational scenario. The scenario was based on personnel escaping a breached collective protection shelter, traveling to a new protection shelter in a vehicle, and processing into the new shelter.

Design. The experimental design was established by the U.S. Air Force to meet specific mask evaluation criteria specified in the Military Specifications document. A 2 X 4 repeated

measures design was employed with two environments and four experimental sessions. The two environmental conditions consisted of a cold climate (-29°C, 30% RH) and a hot climate (52°C, 30% RH). Four experimental sessions were conducted in each environment. In the first session in each thermal condition, subjects did not wear masks. Physiological and psychological data collected during these sessions were used as baseline measurements. In the other three trials (six sessions; three heat, three cold), the three prototype masks were worn by each subject.

Conditions. The subjects were tested concurrently wearing the same type of mask which were assigned in a randomized order. Each test session was separated by at least 2 days to reduce treatment interaction and thermal acclimation. The subjects alternated environmental exposures, with the cold exposure first.

Physiological Measurements. HR, rectal temperature (T_{re}) and T_{sk} were continuously recorded throughout the trials. HR was measured digitally by the Q-Tel Telemetry System (Quinton Instrument Co.). T_{re} and T_{sk} were continuously measured by an Omega TempScan 100 (12-bit) Squirrel Meter/Logger (Science/Electronics; Miamisburg, OH). Each subject inserted a disposable rectal thermistor to a depth of 15 cm (6 in.) beyond the anal sphincter to measure T_{re}. Each subject had 10 skin thermistors placed on specific body sites and held in place by Hy•tape®. These body sites were: cheek, chest, back, forearm, hand, thigh, calf, foot, forehead, and earlobe. The skin thermisters were connected to the digital datalogger for continuous visual monitoring and recording data. The temperatures were scanned once per minute with 0.01°F accuracy.

Attempts were made to measure CO_2 levels and breathing resistance inside the mask at specified intervals, at the end of each exercise bout and every 30 min during rest. CO_2 was measured with a Beckman LB-2 CO_2 Analyzer situated outside the environmental chamber. A Tygon® neoprene tube (0.25 ID) was placed inside the mask near the mouth and connected to the analyzer. Breathing resistance was estimated as the differential pressure between the mask interior and the environment. A Validyne Low Flow Pressure Transducer was connected to a chart recorder outside the chamber.

Psychological Measurements. Rating of Perceived Exertion (RPE) (Borg, 1970) and

Thermal Sensation (TS) (Gagge et al., 1967) were used to measure perceptual responses. These are subjective indicators of stress and discomfort experienced by the subjects measured on a numerical scale. RPE (Appendix A) estimated how hard the subject felt he was working; whereas the TS (Appendix B) indicated how hot or cold the subject felt. Additionally, the subjects' personal reactions to the effects of the masks were recorded and videotaped after each trial was completed.

Procedures

Familiarization Trial. Prior to the eight trials, data were collected during one trial in a thermoneutral environment (21°C, 55% RH) to familiarize the subjects with the procedures and to collect baseline data. Additionally, determination of the treadmill speed and grade required to produce an energy expenditure of 500 W (as prescribed by the U.S. Air Force) was calculated for each subject. This gave a work rate which was validated by open-circuit spirometry (Douglas Bag method) using Ametek Analyzer S-3A/I Oxygen and CD-3A CO_2 Analyzers.

Exercise Protocol. Prior to entering the chamber, the subjects were instrumented with the HR monitor, skin thermistors, and the rectal thermistor. After entering the chamber, subjects remained seated for 15 min to adjust to the temperature. Each complete trial consisted of the subjects: (1) donning the DERP mask, (2) walking on the treadmill for 10 min at the prescribed speed and grade to elicit an energy expenditure of 500 W, (3) sitting quietly for 100 min, and (4) walking again on the treadmill at 500W for 10 min. The subjects were then removed from the chamber, doffed the mask, and were monitored for 30 to 60 min during recovery in a temperate environment (23°C, 30% RH). During recovery, the subjects underwent a debrief relating to comfort and any breathing difficulties experienced while wearing the mask.

Data Collection.

A mean-weighted $\bar{T}_{sk}$ was calculated from six of the 10 skin temperature sites using the Nishi & Gagge equation (1970):

$$T_{sk} = 0.175T_{chest} + 0.225T_{forehead} + 0.18T_{back} + 0.005T_{hand} + 0.195T_{anterior\ thigh} + 0.22T_{lateral\ calf}$$

Statistics.

Due to the limited availability of masks available only two subjects were tested. Thus no statistical analyses were performed.

RESULTS

Subjects wearing the Draeger and ILC masks in the cold completed the 2-hr protocol. The MSA mask cold test was terminated after 5 min of the first rest period for one subject and after 30 min of rest for the other subject. Termination was due to discomfort and improper fit of the mask. All three tests in the heat ended prematurely for both subjects. The stay times for the Draeger, ILC, and MSA masks averaged 40, 47, and 30 min, respectively. Subjects reported that termination was a result of the extreme heat and discomfort, such as facial sweating, while wearing the masks.

The figures below show measurements for each subject during each experimental trial. HR during the cold trials (Figures 1 and 2) showed a slight increase over time during rest except for the ILC for Subject 1 which was approximately equal to or lower than the other two masks and the pretest. During the heat trials (Figures 3 and 4), HR increased over time, with variation among the trials for Subject 1. The values for both subjects were slightly higher during the no-mask trial.

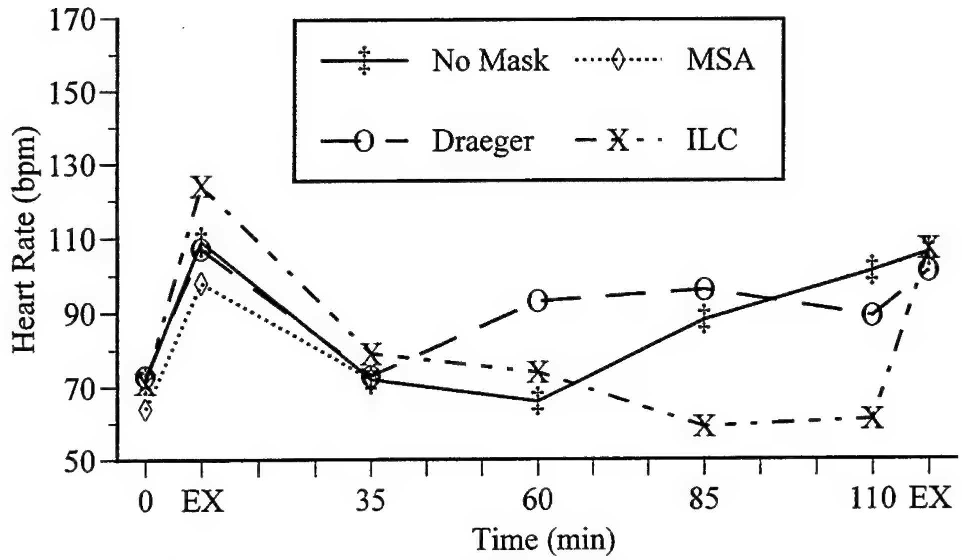

Figure 1: Heart rate during all cold trials for Subject 1

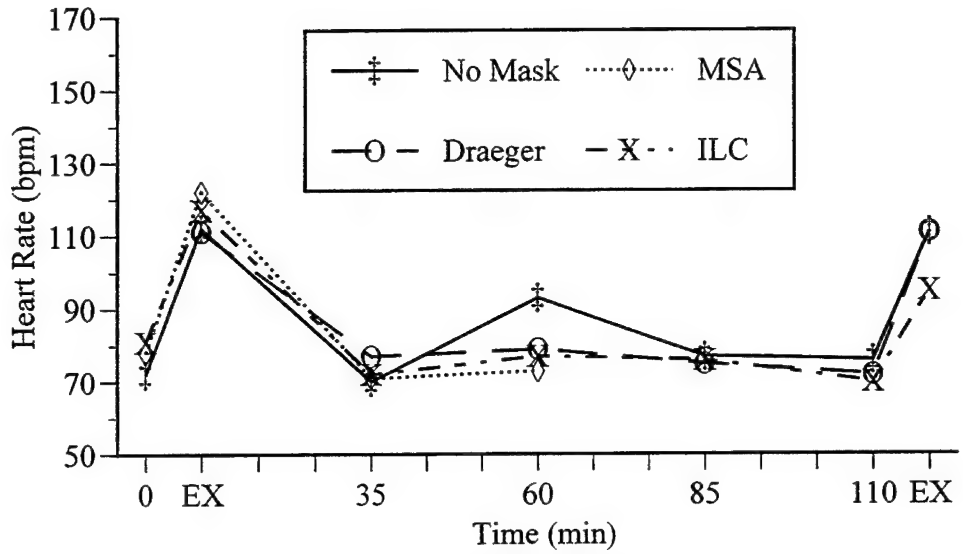

Figure 2: Heart rate during all cold trials for Subject 2

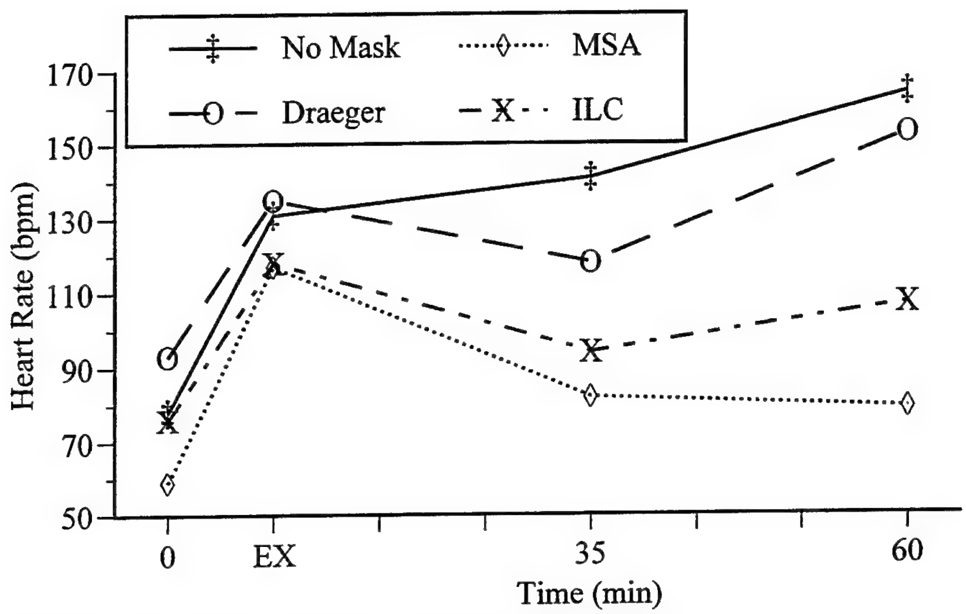

Figure 3: Heart rate during all heat trials for Subject 1

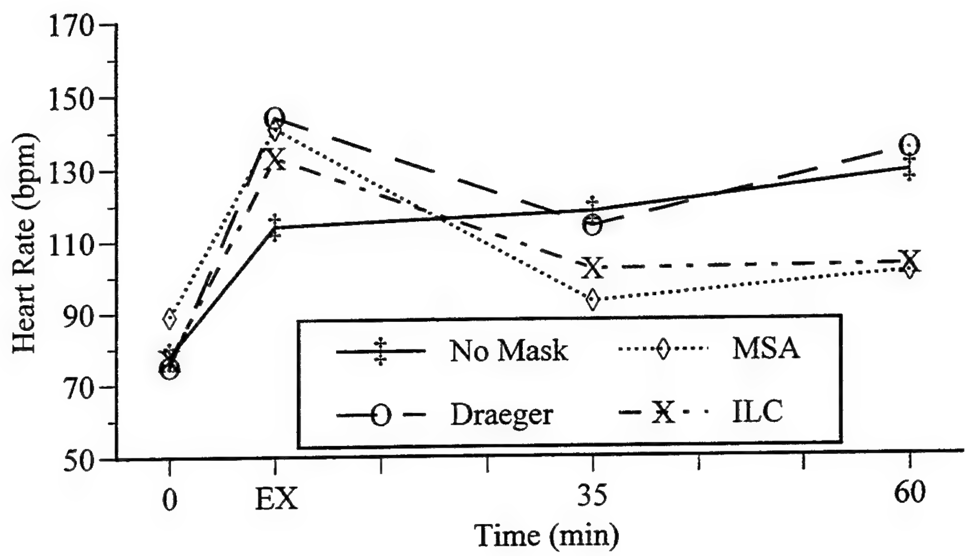

Figure 4: Heart rate during all heat trials for Subject 2

T_{re} during the cold trials (Figures 5 and 6) was similar for both subjects during each trial. T_{re} decreased slightly over the course of the exposure. T_{re} increased during the course of the heat trials (Figures 7 and 8). The subjects had slightly lower T_{re} during all three mask trials in the heat compared to the no-mask trial.

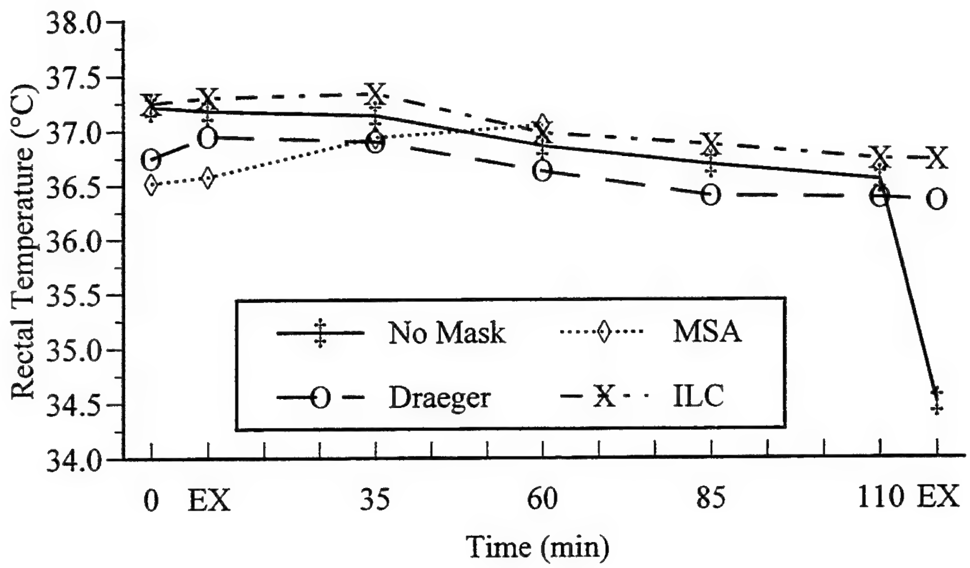

Figure 5: Rectal temperature during all cold trials for Subject 1

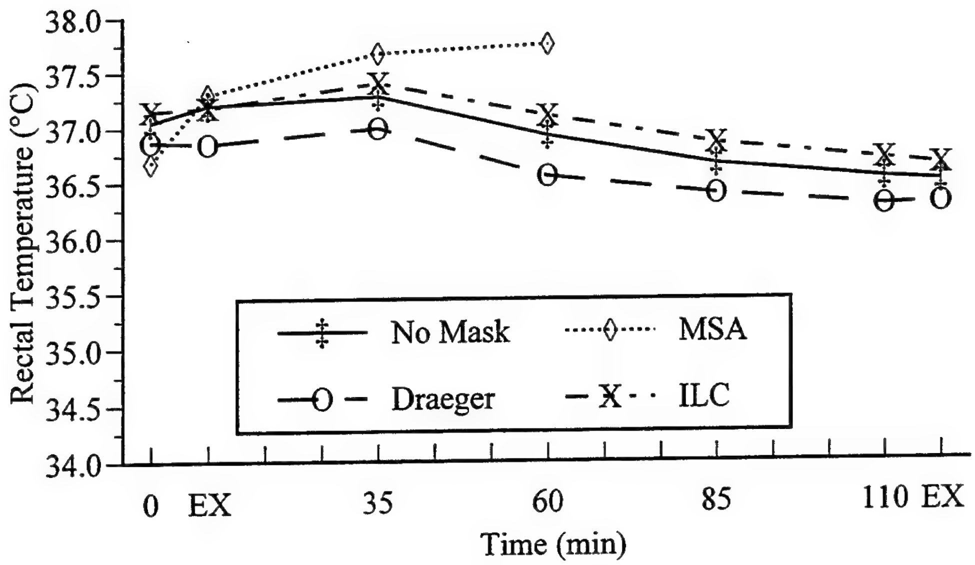

Figure 6: Rectal temperature during all cold trials for Subject 2

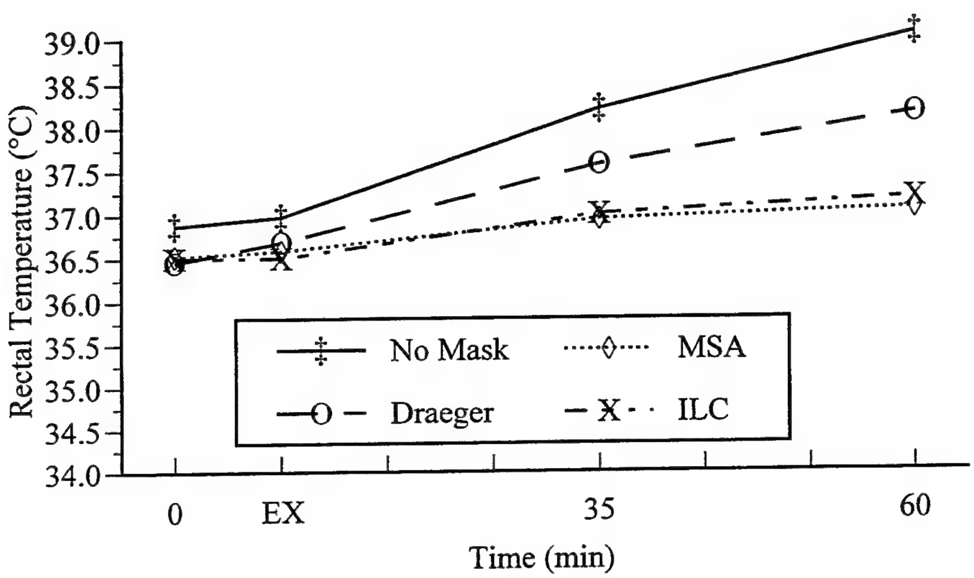

Figure 7: Rectal temperature during all heat trials for Subject 1

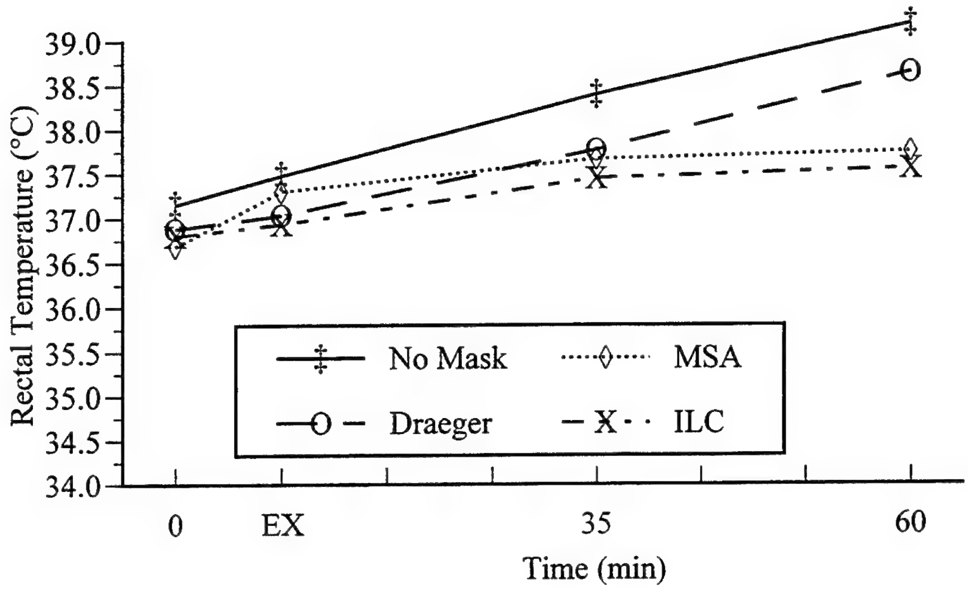

Figure 8: Rectal temperature during all heat trials for Subject 2

Figures 9 and 10 present the $\bar{T}_{sk}$ during the cold trials. $\bar{T}_{sk}$ tended to drop slightly over time with no discernable difference among the mask trials. Figures 11 and 12 demonstrate that the $\bar{T}_{sk}$ in the heat increased only slightly, or not at all, over time with no difference among the mask trials.

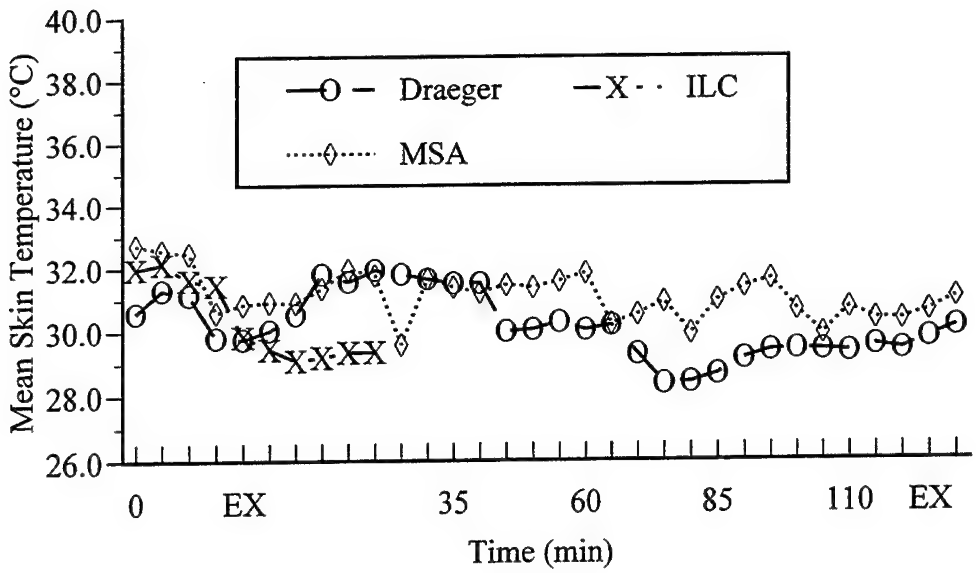

Figure 9: Mean skin temperature during all cold trials for Subject 1

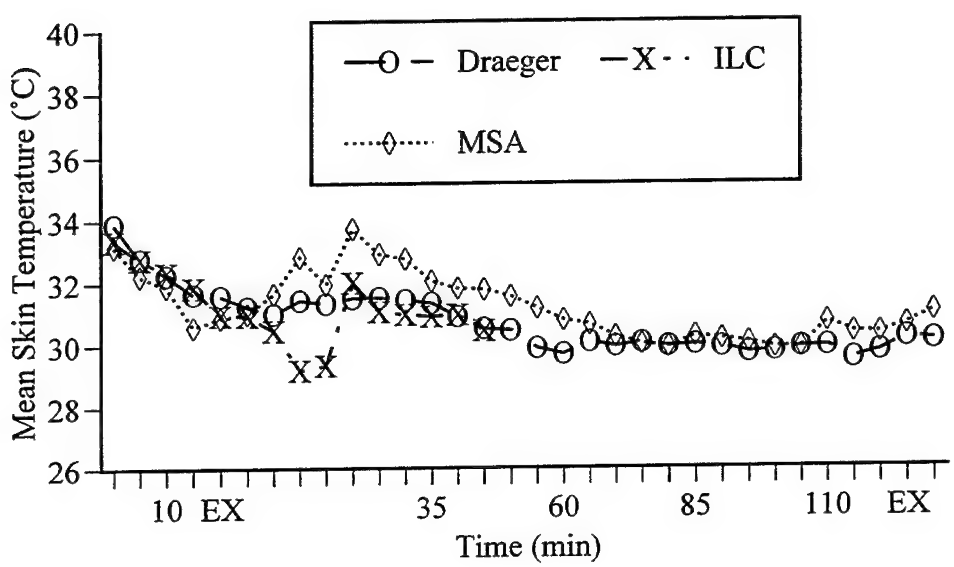

Figure 10: Mean skin temperature during all cold trials for Subject 2

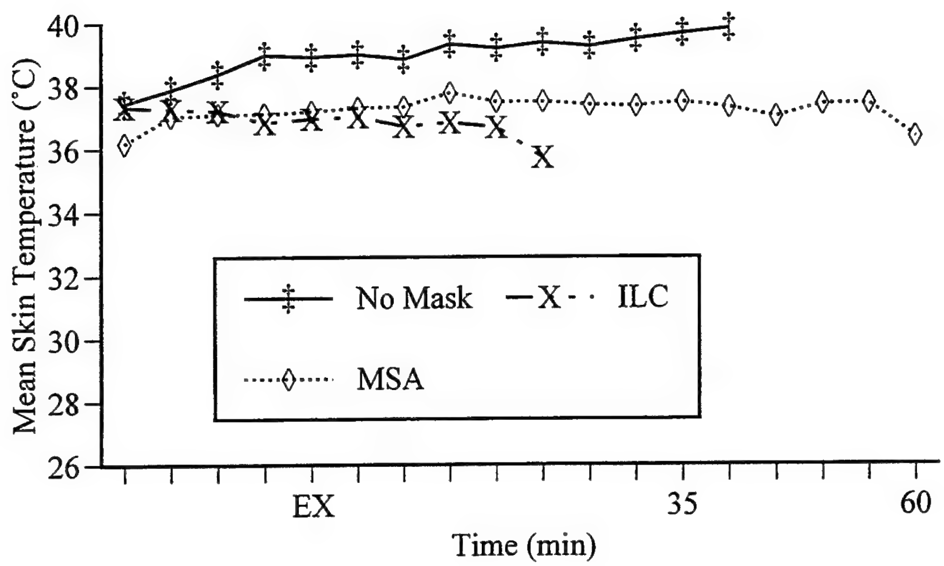

Figure 11: Mean skin temperature during all heat trials for Subject 1

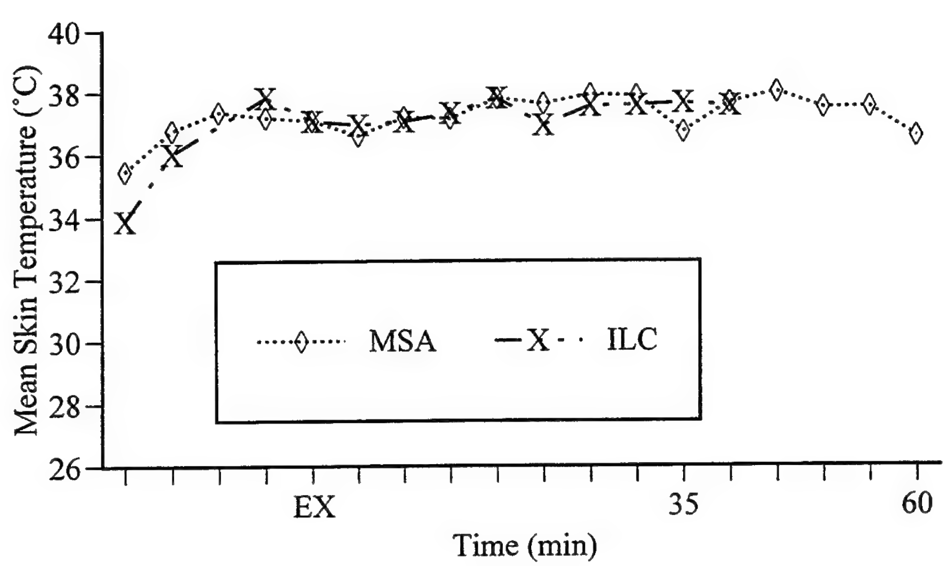

Figure 12: Mean skin temperature during all heat trials for Subject 2

CO_2 responses obtained during the cold and heat trials were limited due to unforeseen problems, such as ice crystals forming inside the collecting tube causing a reduced or unmeasurable gas flow from the mask to the analyzer. This situation could not be rectified during the trial, thus there was no breathing data acquired during this trial. This limited data as seen in Tables 1 and 2, did show however that all values collected were within the ≤4% CO_2 range specified by the U.S. Air Force. Similar results were seen for the resistance data in the cold and in the heat trials. In the heat, the subjects experienced a higher resistance while wearing the MSA mask versus the Draeger, with no data collected on the ILC mask. In the cold, the resistance in the ILC was higher than the MSA mask, with no data collected on the Draeger mask.

TABLE 1. CO_2 for each subject during cold trials

	SUBJECT	NO MASK	DRAEGER	MSA	ILC
EXERCISE PERIOD 1 1 MIN	1 2	5.47 4.38	N/A	N/A	1.30 2.55
EXERCISE PERIOD 1 10 MIN	1 2	5.78 4.34	N/A	4.05	N/A
REST 30-35 MIN	1 2	4.23 3.64	N/A	N/A	3.35 3.65
REST 60-65 MIN	1 2	3.62 3.13	N/A	N/A	3.03 3.22
REST 90-95 MIN	1 2	4.27 3.54	N/A	N/A	3.10 3.48
EXERCISE PERIOD 2 10 MIN	1 2	5.67 4.62	N/A	N/A	3.05 3.11

TABLE 2. CO_2 for each subject during heat trials

	SUBJECT	NO MASK	DRAEGER	MSA	ILC
EXERCISE PERIOD 1 10 MIN	1 2	4.72 4.44	2.60 2.42	0.08 0.10	4.43 2.51
REST 30-35 MIN	1 2	2.79 3.13	3.27 3.76	3.48 0.56	5.11 4.02
REST 40-45 MIN	1 2	N/A	N/A	N/A	5.25

Table 3 lists psychological data collected during the cold trials. The RPE and TS remained fairly steady over time indicating they perceived the effort as light to fairly light throughout and became slightly colder as the trial progressed.

TABLE 3. RPE and TS for each subject during cold trials

		RPE	RPE	RPE	RPE	TS	TS	TS	TS
	SUB-JECT	NO MASK	DRAE-GER	MSA	ILC	NO MASK	DRAE-GER	MSA	ILC
BASELINE	1	6	6	6	6	1	-1	0	0
	2	6	6	6	6	0	0	0	1
EXERCISE PERIOD	1	9	8	7	7	-1	0	0	0
1	2	7	9	7	6	1	1	1	1
REST	1	6	6	6	6	-1	-1	0	0
1 TO 25 MIN	2	6	6	6	7	0	-1	0	1
REST	1	6	6	N/A	6	-1	-1	N/A	0
26 TO 50 MIN	2	6	6		6	1	-1	0	0
REST	1	6	6	N/A	6	-1	-1	N/A	0
51 TO 75 MIN	2	6	6		6	-1	-2		-1
REST	1	6	6	N/A	6	-1	-1	N/A	0
76 TO 100 MIN	2	6	6		6	-2	-2		-1
EXERCISE PERIOD	1	9	6	N/A	6	0	-1	N/A	0
2	2	7	8		7	-1	-1		-1

RPE=Rating of perceived exertion; TS=Thermal sensation

Table 4 lists perceptual data during the heat trials. The RPE indicated the subjects' effort was somewhat hard, even at rest, and the TS indicated they were feeling hot. The trend over time indicated the perceived effort of the subjects was increased under all mask trials. Additionally, the subjects became very hot and were uncomfortable irrespective of the mask they were wore.

TABLE 4. RPE and TS for each subject during heat trials

		RPE	RPE	RPE	RPE	TS	TS	TS	TS
	SUB-JECT	NO MASK	DRAE-GER	MSA	ILC	NO MASK	DRAE-GER	MSA	ILC
BASELINE	1	6	6	6	6	2	1	1	1
	2	6	6	6	6	1	1	1	1
EXERCISE PERIOD 1	1	10	9	9	8	2	2	2	2
	2	8	12	7	8	2	3	2	2
REST 1 TO 25 MIN	1	10	10	7	9	4	3	1	4
	2	7	13	7	9	3	4	2	3
REST 26 TO 50 MIN	1	13	15	7	11	4	4	1	4
	2	12	15	8	12	4	4	3	4

RPE=Rating of perceived exertion; TS=Thermal sensation

DISCUSSION

The recent war in the Persian Gulf revealed that the threat of a chemical/biological attack upon the U.S. military is real. If chemical/biological warfare occurs, it can occur anywhere in the world, not only in the heat of the desert. Therefore, the purpose of this study was to conduct a preliminary evaluation of three prototype DERP masks under consideration for use by the U.S. Air Force under two environmental extremes.

Wearing a gas mask can have detrimental effects on the wearer. Due to the increased breathing resistance and the resulting hypoventilation, the wearer can experience shortness of breath, claustrophobia, and in warm and hot environments, sweat accumulation on the face. These reactions can lead to anxiety, confusion, and/or panic (Ryman et al., 1988). For the present study, divers were asked to participate because they would be comfortable wearing masks. If they were uncomfortable, military personnel with less experience wearing masks could exhibit increased HR, stress, and discomfort. The added stress of a chemical/biological threat in a real-life scenario, would likely cause a decrease in combat effectiveness and could reduce the chance of survival.

Subjects were unable to complete the 2-hr tests in the heat. The discomfort associated with wearing a mask may be more noticeable in a warm environment. The addition of a chemical/biological mask and its associated hood will increase the heat stress experienced in these environments. The added heat stress can limit performance by increasing HR, body temperatures, and subjective levels of exertion (Muza, 1986).

Exposure to the cold environment did not pose as great a stress as did the hot environment. In the cold, the subjects were well insulated and felt comfortable, as indicated by their physiological and perceptual responses and their posttrial comments.

Based on the physiological, psychological, and anecdotal data gathered from the subjects, it was judged that the Draeger mask performed better than the other masks. Overall, the effects of wearing the masks on HR and body temperature, and subjective responses and feelings of exertion and comfort of the subjects were marginally satisfactory for the Draeger and unsatisfactory for the MSA and ILC.

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APPENDICES

APPENDIX A

BORG 15-POINT RATING OF PERCEIVED EXERTION SCALE

BORG 15-POINT RATING OF PERCEIVED EXERTION SCALE

20

19 VERY VERY HARD

18

17 VERY HARD

16

15 HARD

14

13 SOMEWHAT HARD

12

11 LIGHT

10

9 VERY LIGHT

8

7 VERY VERY LIGHT

6

APPENDIX B

THERMAL SENSATION SCALE

THERMAL SENSATION SCALE

HOW DO YOU FEEL NOW?

+4 VERY HOT

+3 HOT

+2 WARM

+1 SLIGHTLY WARM

0 NEUTRAL

-1 SLIGHTLY COOL

-2 COOL

-3 COLD

-4 VERY COLD

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATE COVERED
	2 Dec 1996	Final March-Oct 1996

4. TITLE AND SUBTITLE
The Effects of Wearing a Disposable Eye/Respiratory Protection (DERP) Mask in Environmental Extremes

5. FUNDING NUMBERS
Program Element:
Work Unit Number:
USAF Reimbursable-6515

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San Diego, CA 92186-5122

8. PERFORMING ORGANIZATION
Report No. 97-9

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Medical Research and Development Command
National Naval Medical Center
Building 1, Tower 2
Bethesda, MD 20889-5044

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT *(Maximum 200 words)*

The use of a Disposable Eye/Respiratory Protection (DERP) hood and mask was proposed to provide head, eye, neck, and respiratory protection on an emergency basis when normal protective equipment is not immediately available. Two parameters affecting military work performance while wearing a chemical/biological mask are carbon dioxide (CO_2) and environmental stress. The present study evaluated three prototype DERP masks (Draeger, ILC, and MSA) under consideration for use by the U.S. Air Force. Two subjects followed a 2-hr rest and exercise scenario in two environmental conditions, cold air (-29°C, 30% RH) and hot air (52°C, 30% RH) while wearing the three prototype masks. CO_2 level and breathing resistance inside the masks were analyzed in addition to the thermal, physiological, and psychological effects. The 2-hr scenario in the cold was well tolerated by the subjects; however the 2-hr scenario in the heat was too stressful. The CO_2 level and breathing resistance inside the Draeger and MSA masks were considered satisfactory and unsatisfactory for the ILC mask based on U.S. Air Force standards. Overall, the effects of wearing the masks on HR and body temperature, and subjective responses and feelings of exertion and comfort of the subjects were marginally satisfactory for the Draeger and unsatisfactory for the MSA and ILC.

14. SUBJECT TERMS
battle dress uniform, chemical protective outergarment, chemical/biological mask, chemical warfare, biological warfare, heat, cold, respiratory, breathing, temperature

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102